Topic B – Part 8
Nucleic Acids

IB Chemistry

Topic B – Biochem

B8 Nucleic acids - 3 hours

- B.8.1 Describe the structure of nucleotides and their condensation polymers (nucleic acids or polynucleotides). (2)
- B.8.2 Distinguish between the structures of DNA and RNA. (2)
- B.8.3 Explain the double helical structure of DNA. (3)
- B.8.4 Describe the role of DNA as the repository of genetic information, and explain its role in protein synthesis. (2)
- B.8.5 Outline the steps involved in DNA profiling and state its use. (2)

B8.1 – Structure of Nucleic Acids

- B.8.1 **Describe** the structure of nucleotides and their condensation polymers (nucleic acids or polynucleotides). (2)
- Living cells contain two different types of nucleic acids
  - **DNA** (deoxyribose nucleic acid)
  - **RNA** (ribose nucleic acid)
- **Nucleic Acids** are made up of **Nucleotides** which contain three smaller types of molecules that are covalently bound together under enzyme control
    - Phosphate
    - Pentose sugar
    - Base

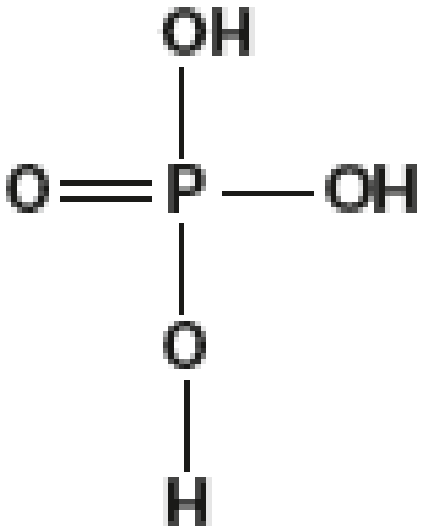
B8.1 – Nucleotides (phosphate)

- The **phosphate** group is a chemically reactive functional group that allows new molecules to be added via a condensation reaction.
- Hence, nucleotides can form long chains (linear polymers).
- The phosphate groups are ionized and partially responsible for the solubility of nucleic acids in water

B8.1 - Phosphate

- Component 1 of a nucleotide is the **phosphate**

phosphoric acid

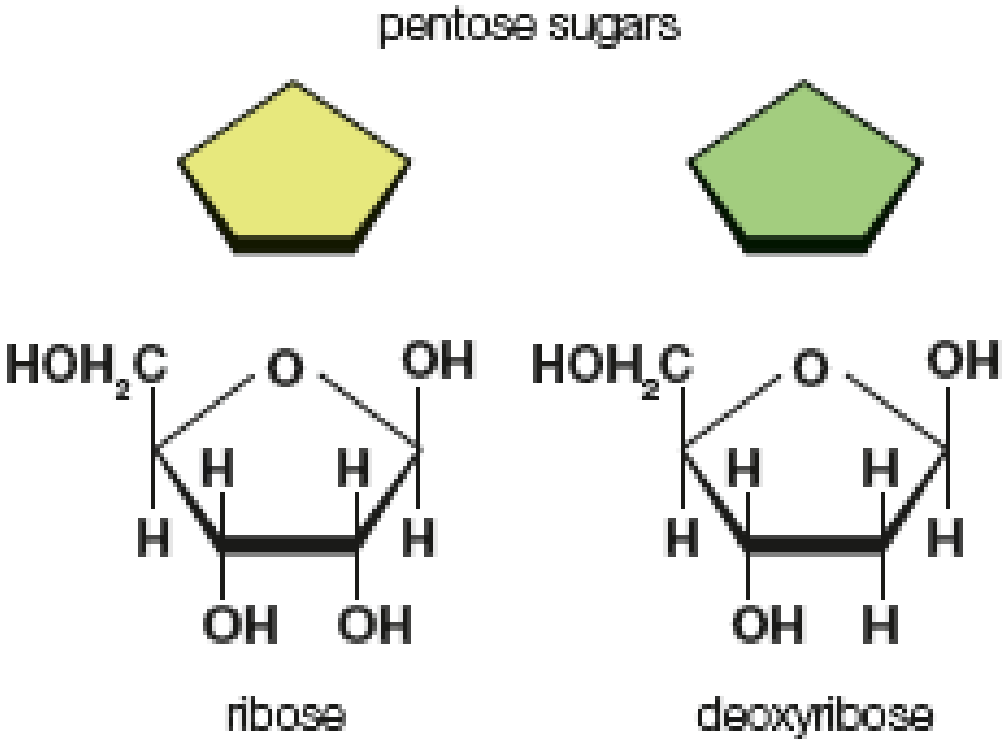


B8.1 – Nucleotides (pentose sugar)

- The second component, **pentose sugar**, is a 5-carbon monosaccharide known as **deoxyribose** in DNA and **ribose** in RNA
- These sugars are chemically reactive and are involved in bonding different nucleotides together via condensation reactions with –OH groups at carbons 1 and 5

B8.1 – Pentose Sugar

- Component 2 of a nucleotide is the **pentose sugar**

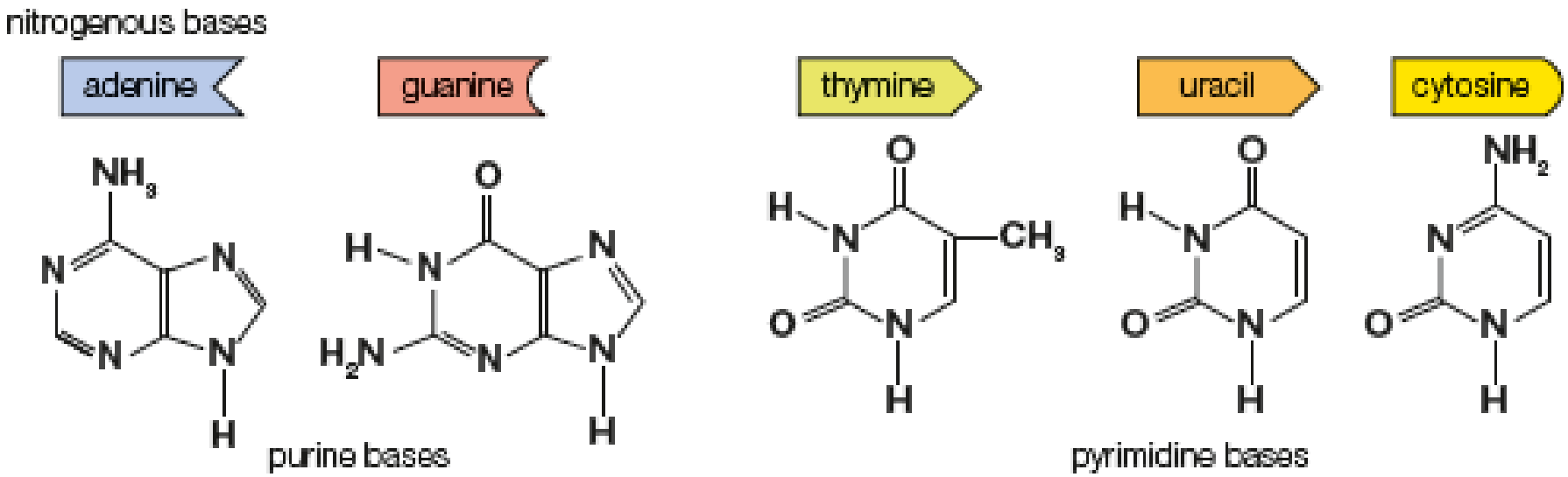


B8.1 – Nucleotides (base)

- The **base**, the third component, is covalently bonded to the pentose sugar via the carbon atom in position 1 of the ring.
- Four different bases are found in DNA:
  - **Adenine (A)**
  - **Thymine (T)**
  - **Guanine (G)**
  - **Cytosine (C)**
- Cells continuously synthesize nucleotides and these form a 'pool' in the cytoplasm from which nucleotides can be used by the cell for synthesizing DNA

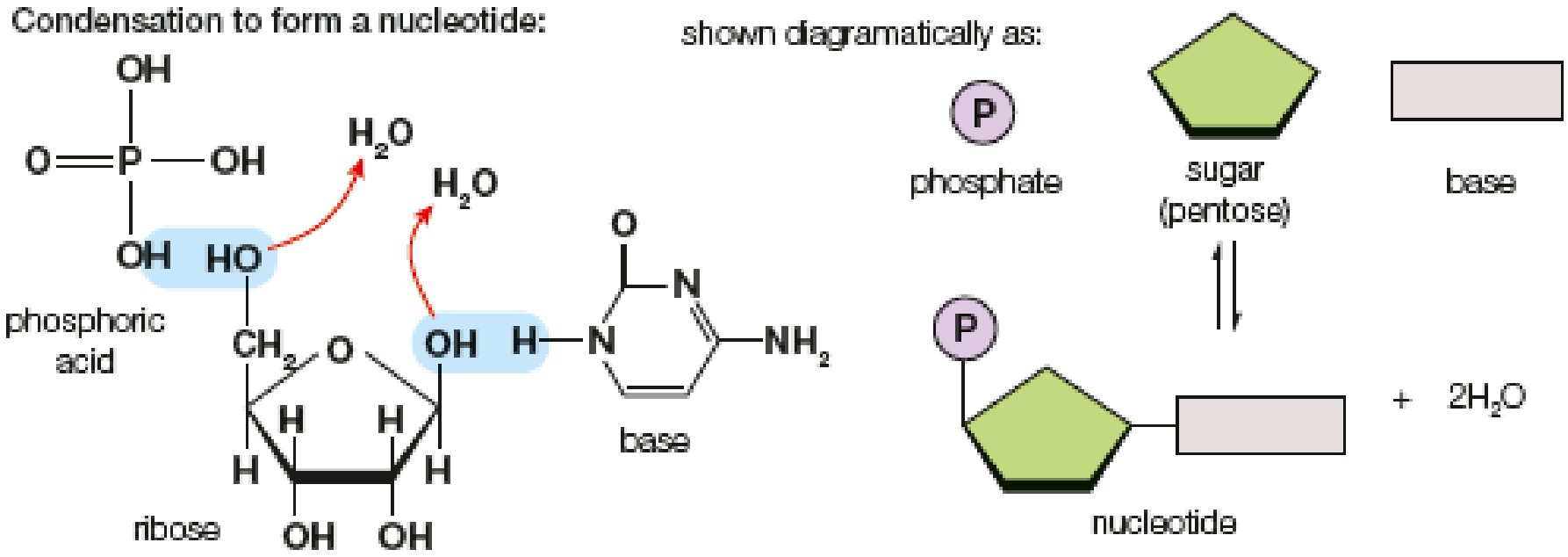
B8.3 - Base

- Component 3 of a nucleotide is the **base** present



B8.1 – Formation of Nucleotide

- Nucleotides are formed from all three components, a phosphate, pentose sugar, and base



B8.2 – DNA vs RNA structure

- B.8.2 **Distinguish** between the structures of DNA and RNA. (2)
- Both DNA and RNA molecules are polynucleotides
- RNA is considerably **shorter** than DNA molecules
- In RNA, all of the nucleotides include **ribose**
- In RNA, bases are adenine cytosine (**C**), guanine (**G**), adenine (**A**), and uracil (**U**). *(T only in rRNA)*
- In living cells, three main functional types of RNA, all are directly involved in **protein synthesis**
  - Messenger RNA (**mRNA**)
  - Transfer RNA (**tRNA**) (single/double helix)
  - Ribosomal RNA (**rRNA**) (single/double helix)

B8.2 – DNA vs RNA

- **DNA** molecules occur in the **chromosomes** and form very **long strands**, containing **several million nucleotides**
- All DNA molecules contain **deoxyribose** (~~not ribose~~)
- In DNA, the bases are cytosine (**C**), guanine (**G**), adenine (**A**), and thymine (**T**). instead of ~~uracil (U)~~
- Consist of two polynucleotide strands held by hydrogen bonding = **double helix**

B8.2 – DNA vs RNA

Summary of DNA vs. RNA

DNA	RNA
Generally very long strands, several millions of nucleotides long	Relatively short strands, 100 to 1000 nucleotides long
Contains deoxyribose	Contains ribose
Consists of two polynucleotide strands of complementary **base pairs**: cytosine (C) with guanine (G), adenine (A) with thymine (T). The strands are held together by hydrogen bonds in the form of a double helix	Messenger RNA is single-stranded; transfer and ribosomal RNA have both single- and double-stranded sections
Relatively stable towards chemicals (especially alkali) and enzymes	Less stable towards chemicals and enzymes

Table 22.10 Summary of the differences between RNA and DNA

B8.3 – Double Helix of DNA

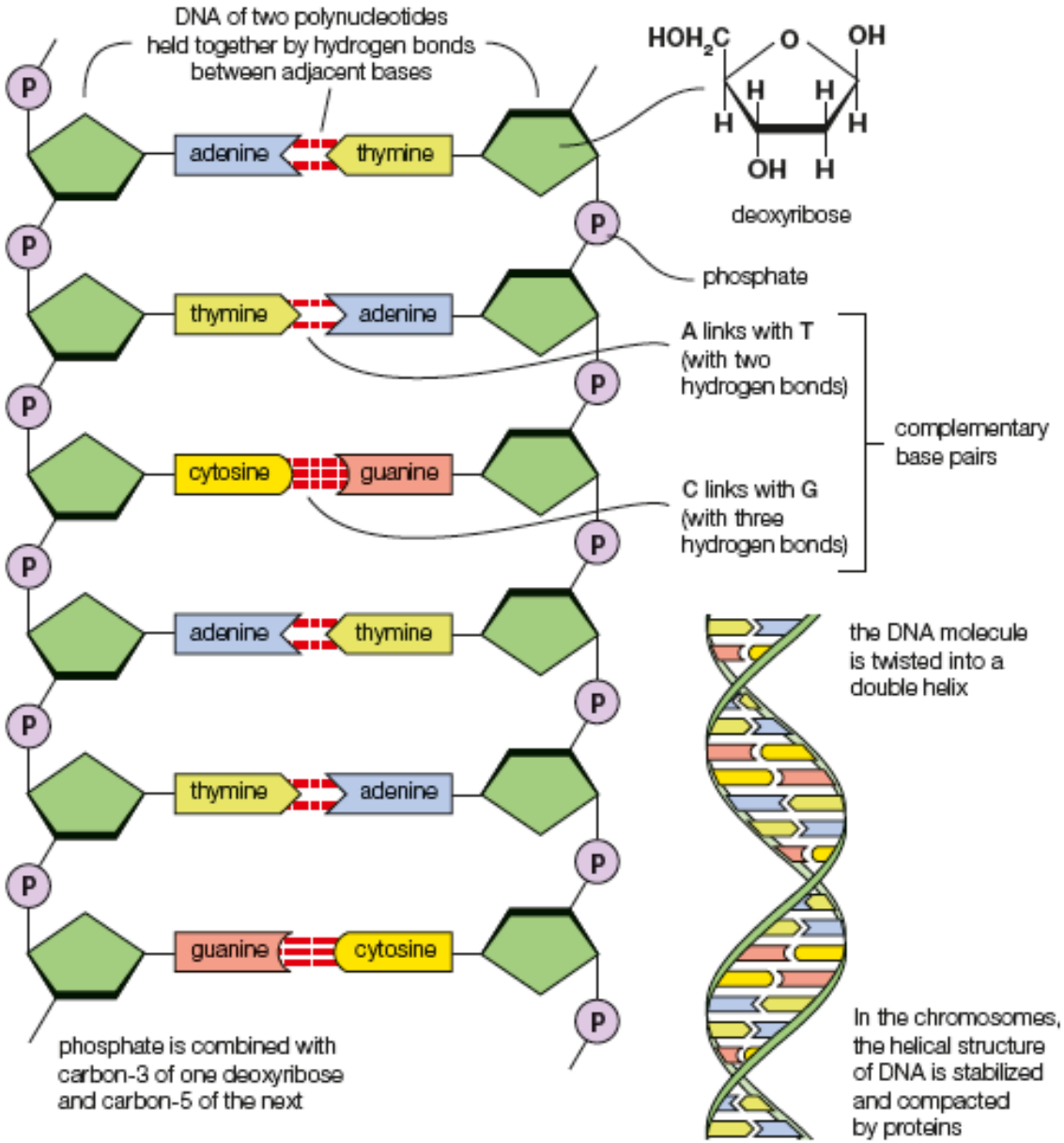
- B.8.3 **Explain** the double helical structure of DNA. (3)
- DNA, history of the name nucleic acid:
  - DNA was first isolated over 100 years ago by a Swiss biochemist, Fredrich Miescher. He was studying white blood cells obtained from the pus on the bandages of patients recovering after operations. A white precipitate was obtained and found to contain the elements C, H, O, N, and P. It came from the nucleus of the cells and experiments showed it to be acidic; so it was given the name 'nucleic acid.'

B8.3 – DNA Structure

- DNA consists of two linear **polynucleotide** strands which are wound together in the form of a **double helix**.
- The double helix is composed of two right-handed helical polynucleotide chains coiled around the same central axis.
- The **bases** are on the **inside** of the helix
- **Sugar-phosphate backbone** on the **outside**
- Two chains held together by **hydrogen bonds** between the **bases** on the two nucleotide chains

B8.3 – DNA Structure

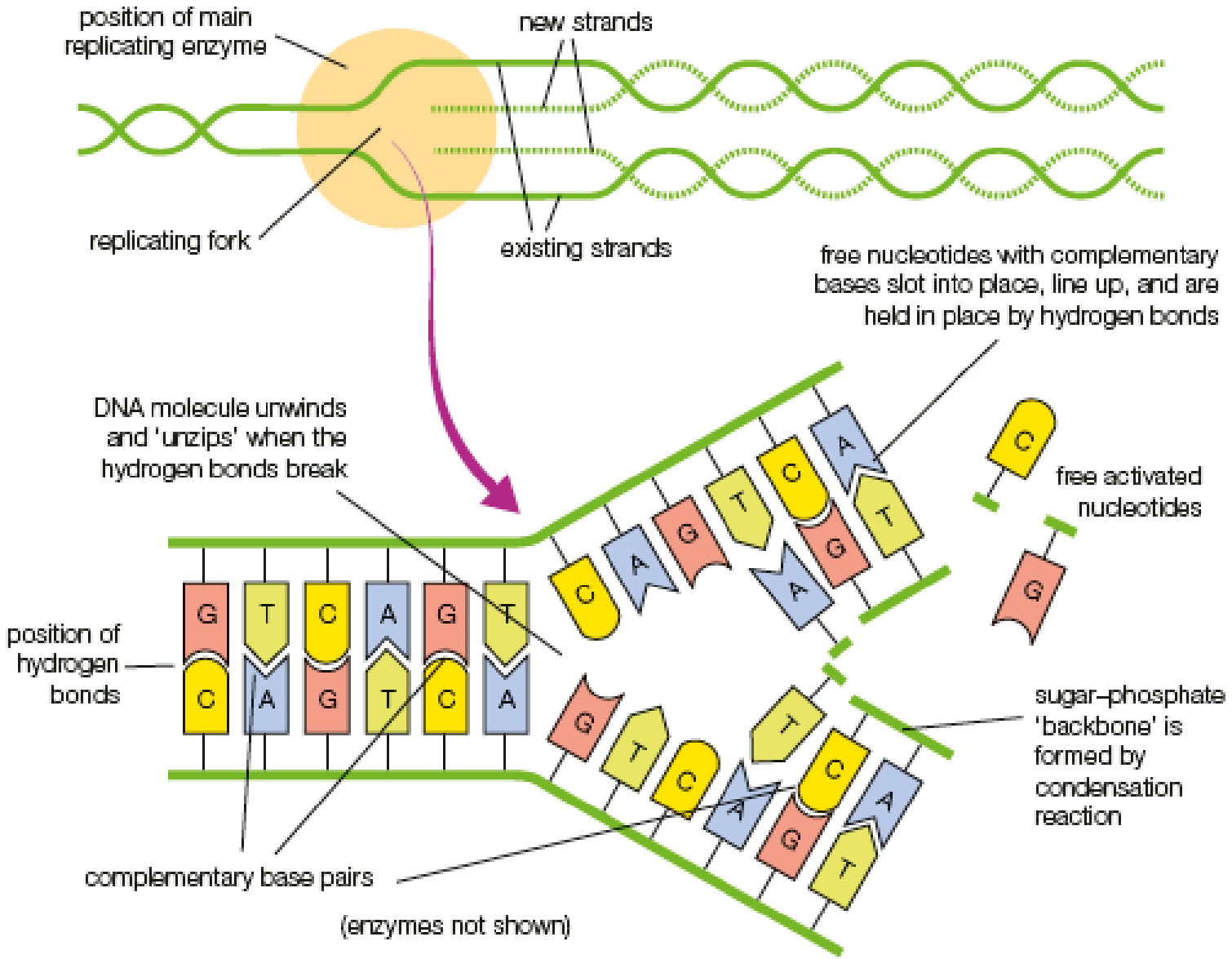
- Pairing is specific, known as **complementary base pairs**
  - T to A
  - C to G
- Complementary base pairing is the underlying basis for the processes of replication, transcription, and translation



B8.3 – DNA Replication

- DNA can duplicate itself in the presence of appropriate enzymes. This process is known as **replication**
- Genetic information inside a cell is coded into the sequence of bases in its DNA molecule
- During cell division, DNA molecules replicate and produce exact copies of themselves
- The two strands are unwound (under enzyme control) and each strand serves as a template patter for the new synthesis of the complementary DNA strand

B8.3 – DNA Replication



B8.4 – Role of DNA

- B.8.4 **Describe** the role of DNA as the repository of genetic information, and explain its role in protein synthesis. (2)
  - DNA is the genetic material that an individual inherits from its parents.
  - It directs mRNA synthesis (transcription) and, through mRNA, directs protein synthesis (translation) using a triplet code.

B8.4 – Protein Synthesis Transcription and Translation

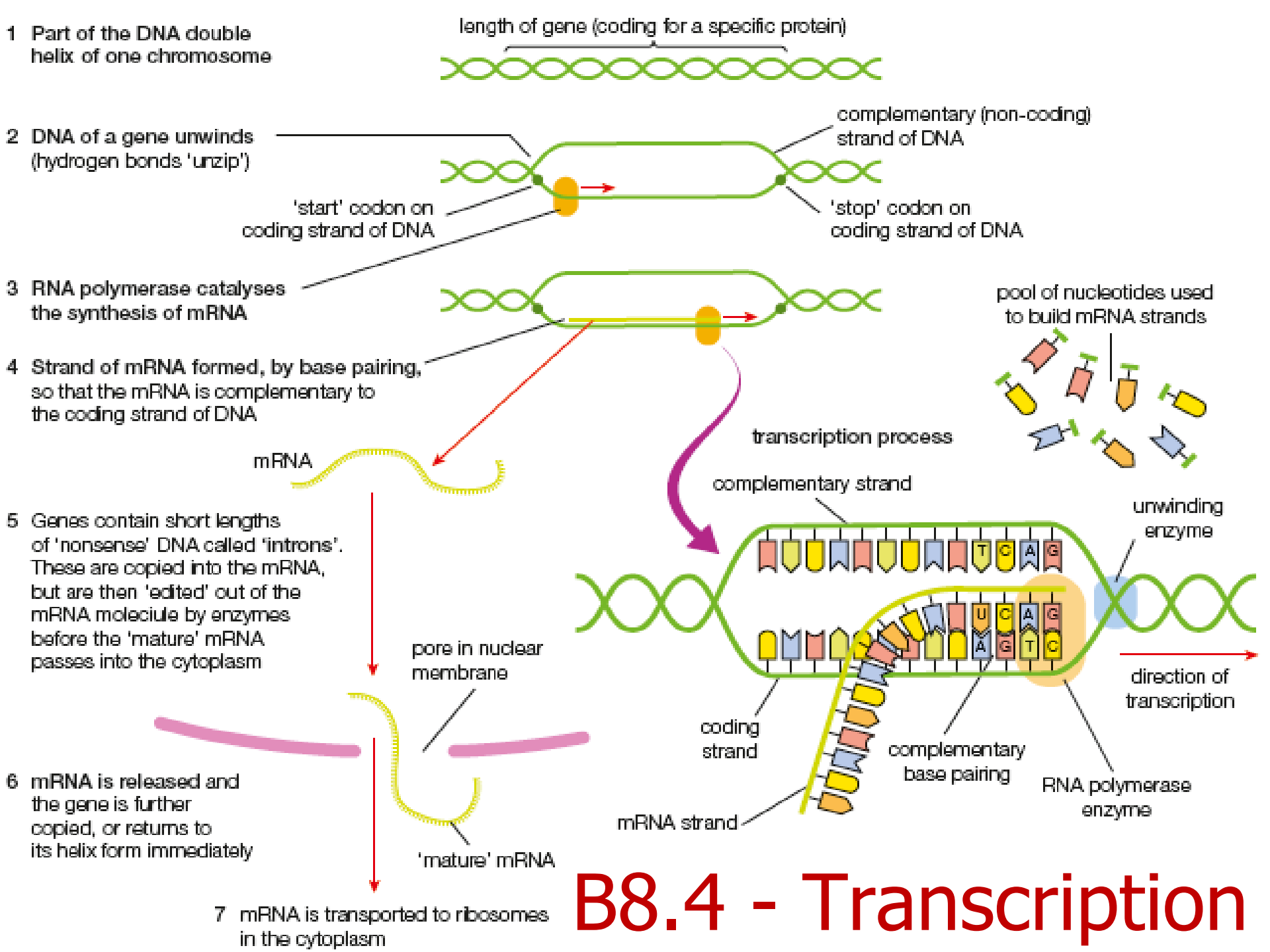
- The DNA molecules in the nucleus of the cell hold the genetic code for protein synthesis.
- Each gene is responsible for the production of a single protein
- The genetic information is coded in DNA in the form of a specific sequence of bases within a gene
- The synthesis of proteins involves two steps
  - **Transcription**
  - **Translation**

B8.4 – Part 1: Transcription

- RNA is a single-stranded molecule that is formed by **transcription** from DNA
- The **DNA molecule separates** into two strands (under enzyme control) to reveal its bases, as in replication.
  - BUT NOW its free **ribonucleotides** (and not deoxyribonucleotides) that base-pair to it and **form an RNA molecule**
  - The RNA molecule, known as **mRNA**, is transported out of the nucleus of the cell and attaches to a cell organelle known as a **ribosome**.

B8.4 - Translation

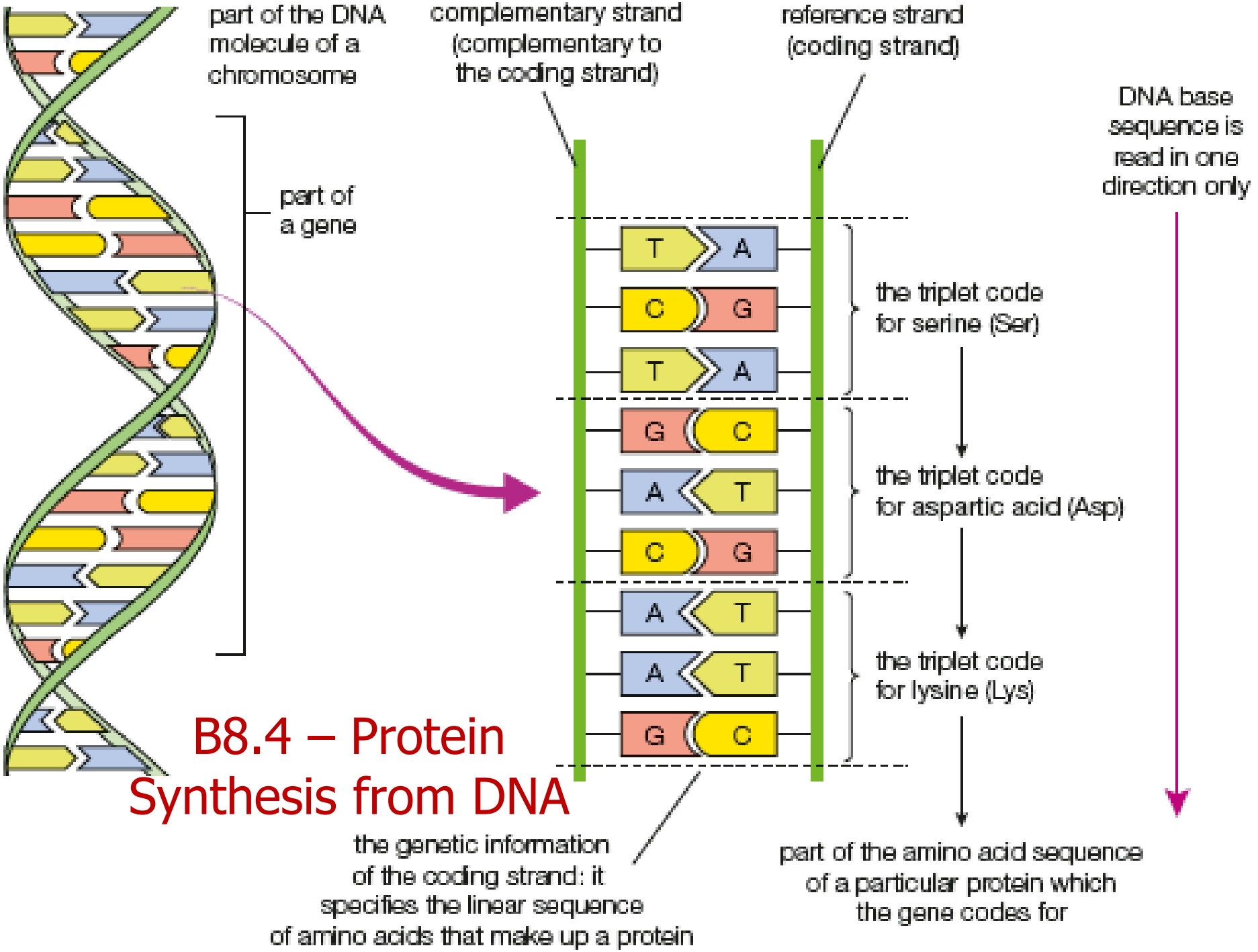
- **Ribosomes** are formed from protein and RNA, and are the sites at which proteins are synthesized from amino acids.
- This process is called **Translation**
- Messenger RNA is responsible for converting the genetic code of DNA into protein



B8.4 - Transcription

B8.4 – Triplet Code for Proteins

- The primary structure of a protein consists of a chain of amino acids connected by peptide links (10 AA's)
- The structure of DNA is from four bases A,G,C,T
- The code for an amino acid (called a **codon**) is a sequence of 3 bases
  - There are then 64 (3^4) different 'triplets'
  - Some amino acids are encoded by +1 codons
  - Of the 64 codons, 61 code for amino acids and three act as 'stop' signals to terminate the protein synthesis when the end of the polypeptide chain is reached



B8.4 – Protein Synthesis from DNA

B8.4 – Ribosomes in Protein Sythesis

- Protein synthesis takes place in ribosomes located in the cytoplasm.
- One end of an mRNA molecule binds to a ribosome, which moves along the mRNA strand three bases at a time (next slide)
- Molecules of another type of RNA, called **transfer RNA** (tRNA), bind to free amino acids in the cytoplasm
- tRNA molecules carry specific AA's, and have their own base triplet, known as **anticodon**, which binds via hydrogen bonding to the complementary codon triplet on the mRNA.

B8.4 – Translation (Protein Synthesis)

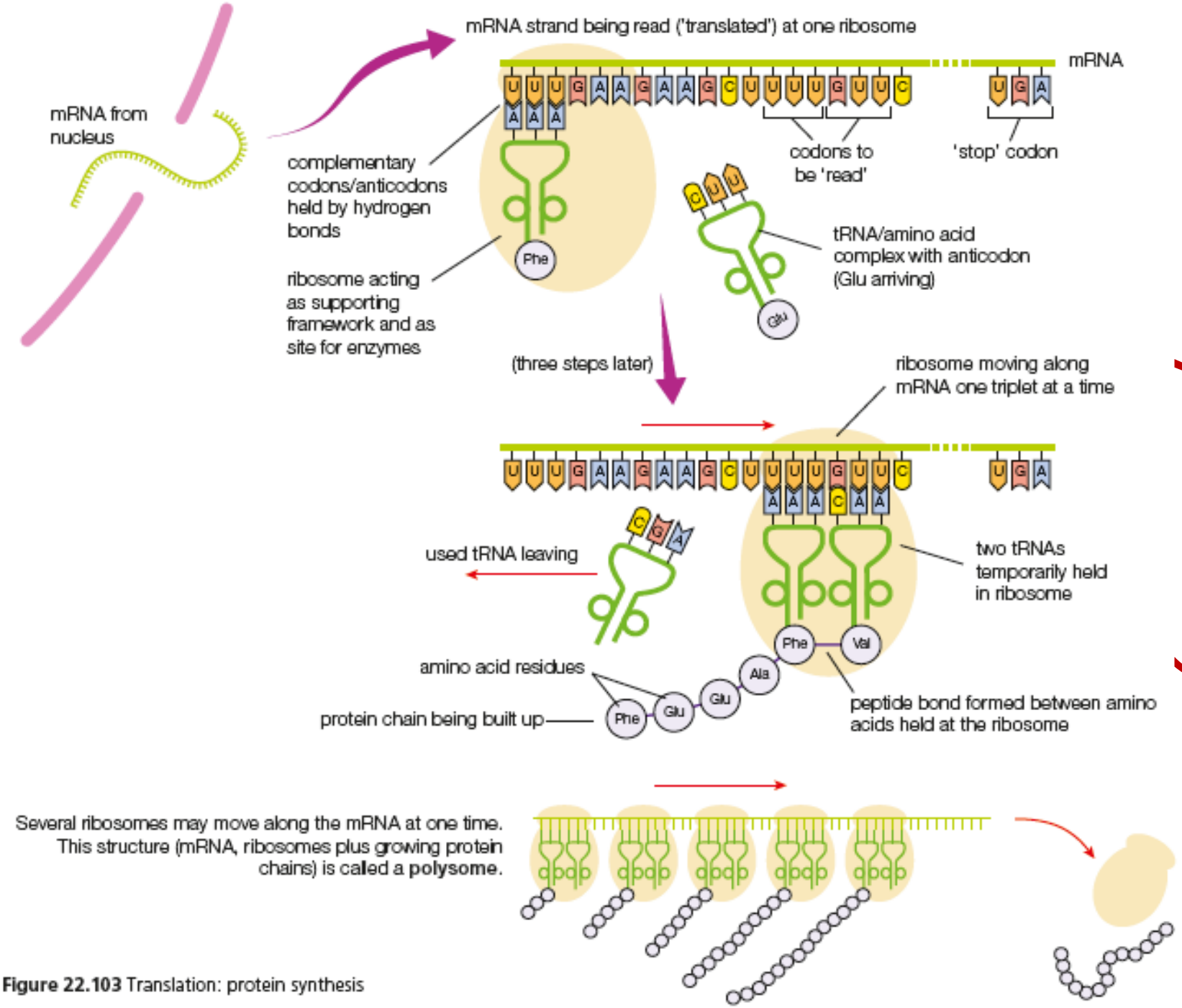
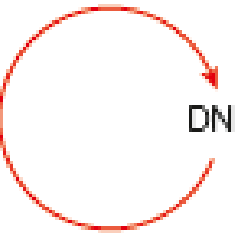


Figure 22.103 Translation: protein synthesis

B8.4 – DNA Self-replication

replication
DNA is self-replicating



DNA

transcription
the base sequence of DNA is copied into a messenger (messenger RNA)

mRNA

translation
information in mRNA is coded into an amino acid sequence

protein

messenger RNA moves from the nucleus to the cytoplasm and is 'read' in ribosomes

B8.5 – DNA Profiling

- B.8.5 **Outline** the steps involved in DNA profiling and state its use. (2)
- DNA profiling uses the techniques of genetic engineering to identify a person from a sample of their DNA (blood, tissue, fluid)
- Crime, paternity, evolutionary relationships, etc
- Large portions of DNA are identical in everyone, but small sections (or fragments) of our human DNA are unique to a particular individual
  - They are non-coding (for proteins) and are termed **polymorphic,** as they vary from person to person

B8.5 – DNA Profiling

1. Sample of cells are obtained, DNA extracted
2. DNA is copied and amplified by automated process called **polymerase chain reaction (PCR)**. Produces sufficient DNA to analyze
3. DNA is then cut into small, double stranded fragments using restriction enzymes which recognize certain sequences of coding and non-coding DNA
4. Fragments (of varying lengths) are separated by gel eletrophoresis into a large number of invisible bands

5. The gel is treated with alkali to split the double-stranded DNA into single strands
6. Copy of the strands is transferred to a membrane and selected radioactively labeled DNA probes are added to the membrane to base pair with particular DNA sequences. Excess washed away.
7. Membrane is overlaid with X-ray film which becomes selectively 'fogged' by emission of ionizing radiation from the based-paired radiolabels
8. The X-ray film is developed, showing up the positions of the bands (fragments) to which probes have been paired

B8.5 – DNA Paternity Matching

- Ignoring the three bands in Eileen's DNA profile which occur in the same position as her mother's, you will see that all four of the remaining bands correspond with those of Tom, but only two matches with those from Harry. It is unlikely that Harry is Eileen's father.